DESCRIPTION

FILM DEPOSITION APPARATUS HAVING HOLE-LIKE ROTARY FILTER PLATE
FOR CAPTURING FINE PARTICLES, AND FILM DEPOSITION METHOD

Technical Field

The present invention relates to deposition systems and
methods for forming layers of various materials, the layers
being formed in such a manner that airborne fine particles
containing a thin film-forming component are generated by
energy beam irradiation or arc discharge and then attached
to substrates. The present invention particularly relates
to a deposition system including a filter for preventing
droplets from adhering to a layer to enhance the quality of
the layer and also relates to a deposition method using such
a filter.

Background Art

In a deposition method for forming a thin film made of
metal, semiconductor, or ceramic on a substrate by a laser
ablation process, a sputtering process, an arc discharge
process, or another process, fine particles (liquid cluster
particles deposited in a thin film) transformed into
droplets need to be prevented from adhering to the substrate.
Known examples of a technique for preventing this problem
include a technique in which the incident angle of a laser
beam applied to a target is controlled to 43 degrees or less

- 1 -

(Patent Document 1) and techniques for rotating targets at high speed (Patent Documents 2 and 3).

In order to prevent surface properties of the thin film from being deteriorated due to the adhesion of the droplets to the substrate, a technique for trapping the flying cluster particles is used. Known examples of such a technique include a technique for attaching high-mass cluster particles to a face of a passage area-controlling member on which fine particle are incident and which have a large number of gaps (Patent Document 4), a technique using a mechanical shutter or a molecular flow shutter (Patent Document 5), deposition techniques using rotary disks which include slits and which serve as mechanical choppers for blocking high- or low-speed atoms (Patent Document 6, 7, and 8), and a technique using a deposition system including a plurality of rotary vanes (for example, Patent Document 9).

In the former one, a laser needs to be synchronized with a filter because the laser beam is pulsed; hence, the range of a selectable speed is limited. In the latter one, the vanes reflect fine particles because the vanes are tilted; hence, the vanes cannot completely trap low-speed fine particles. Since the design of vanes for trapping such low-speed fine particles is severely constrained and it is difficult to arrange a large number of such vanes in a filter, this filter needs to have a large thickness in the flight direction of the fine particles. This leads to an

increase in the distance between a target and a substrate, thereby causing a problem that high-quality layers hardly formed or another problem. Furthermore, there are problems in that the manufacture of the filter requires extremely high techniques, the manufacturing cost thereof is high, and an obtained layer is contaminated with the fine particles that have been trapped and then released.

The inventor has developed a deposition system and deposition method for removing droplets using a high-speed rotary filter and has applied for a patent thereof (Patent Document 10). This filter has problems that it is difficult to completely prevent the release of such droplets and the manufacturing cost of this filter is high.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 06-017237

Patent Document 2: Japanese Unexamined Patent Application Publication No. 07-166331

Patent Document 3: Japanese Unexamined Patent Application Publication No. 2001-107225

Patent Document 4: Japanese Unexamined Patent Application Publication No. 08-176805

Patent Document 5: Japanese Unexamined Patent Application Publication No. 04-202762

Patent Document 6: Japanese Unexamined Patent Application Publication No. 10-030168

Patent Document 7: Japanese Unexamined Patent Application

Publication No. 2001-192811

Patent Document 8: Japanese Unexamined Patent Application Publication No. 2003-277919

Patent Document 9: Japanese Unexamined Patent Application Publication No. 10-030169

Patent Document 10: Japanese Unexamined Patent Application Publication No. 2003-049262

Disclosure of Invention

Problems to be Solved by the Invention

It is an object of the present invention to provide a deposition system and method for forming layers of various materials using a filter, the layers being formed in such a manner that airborne fine particles containing a thin film-forming component are generated in a vacuum vessel and then attached to substrates. The filter is shaped so as to be readily manufactured at low cost, can trap droplets, and can securely prevent the release of trapped fine particles although flat panel filters cannot prevent the release thereof in principle.

Means for Solving the Problems

In order to solve the above problems, a rotary porous filter plate, which is different from a known panel filter, according to the present invention has a configuration in which a disk has a large number of perforations.

The present invention provides a deposition system for
generating airborne fine particles containing a thin film-
forming component to attach the airborne fine particles to a
substrate. The deposition system includes the rotary porous
filter plate, including a disk having a large number of
perforations extending therethrough, rotated on a rotary
shaft connected to the center of the disk at high speed.
The rotary porous filter plate is disposed between the
substrate and a target such that the fine particles flying
through the perforations are deposited on the substrate but
the fine particles which fly low speed and which are
transformed into droplets are trapped in the perforations.
The present invention also provides a deposition method
using the deposition system.

In the system of the present invention, the
perforations each have end portions and an intermediate
portion having a diameter greater than those of the end
portions, the end portions being located close to surface
regions of the rotary porous filter plate. Therefore, the
trapped fine particles can be confined in the perforations
such that the trapped fine particles can be securely
prevented from being released, because the fine particles
trapped in the perforations are gathered at center regions
of the perforations by the rotation of the rotary porous
filter plate. According to the system of the present
invention, the fine particles flying in the perforations at

a speed greater than or equal to a predetermined speed and
the fine particles flying at a speed less than or equal to a
predetermined speed can be both trapped.

Advantages

According to the present invention, a filter can be
manufactured in such a manner that a large number of
perforations are formed in a disk only by chemical or
mechanical processing. The filter, as well as a known panel
filter, can trap fine particles although the filter has a
simple configuration. The trapped fine particles can be
confined in center regions of the perforations by the
rotation of the rotary porous filter plate because the walls
of the perforations are curved; hence, deposition can be
performed without releasing the trapped fine particles.

For layers formed using flat panel filters, fine
particles released from the filters are observed on the
layers. In contrast, for a layer formed using the rotary
porous filter plate of the present invention, no fine
particles released from the filter are observed on the
layer; hence, the layer has high quality. The rotary porous
filter plate can be more precisely manufactured at lower
cost as compared to the flat panel filters.

Best Mode for Carrying Out the Invention

Fig. 1 is a schematic view of an example of a laser

ablation deposition system including a known rotary filter. With reference to Fig. 1, a laser beam 53 focused by a lens 52 is applied to a target 55 mounted on a rotatable target holder 54 disposed in a vacuum vessel, whereby airborne fine particles 56 are generated from the target 55 and then attached to a substrate 58 mounted on a substrate holder 57. The distance between the substrate 58 and the target 58 is preferably about 10 to 100 mm. The target 55 is irradiated with the laser beam 53, whereby the airborne fine particles 56 containing a thin film-forming component are generated and allowed to fly toward the substrate 58. A rotary panel 51 for trapping the fine particles that fly at low speed and that are transformed into droplets is disposed between the target 55 and the substrate 58 and supported by a rotary shaft 59. The rotary panel 51 is rotated at high speed such that the low-speed fine particles are trapped by a portion of the rotary panel 51 that blocks the flight of the fine particles. In a method according to the present invention, a rotary porous filter plate is used instead of the known rotary filter.

Fig. 2 is a schematic perspective view showing an exemplary configuration of the rotary porous filter plate included in a system according to the present invention. A large number of perforations 3 are arranged such that the center lines thereof extend vertically between both faces of the rotary porous filter plate 1 in parallel to the flight

direction of the fine particles. In Fig. 2, the following

faces are parallel to each other: a face of the target

which is not shown (located below the figure), a face of the

substrate which is not shown (located above the figure), and

both faces of the rotary porous filter plate 1. The center

lines of the perforations 3 extend in parallel to a rotary

shaft connected to the rotary porous filter plate 1. When

the rotary porous filter plate 1 is not rotated, the fine

particles flying from the target toward the substrate pass

through the perforations 3 to deposit on the substrate.

The fine particles colliding with a face of the rotary

porous filter plate 1 that faces the target adhere thereto.

This reduces the deposition rate of the fine particles on

the substrate; hence, the sum of the areas of portions of

the perforations 3 is preferably large. When a face of the

rotary porous filter plate 1 is viewed, the percentage of

the sum of the areas of portions of the perforations 3 in

the surface area of the rotary porous filter plate 1 defines

the deposition rate of a layer to be formed. The reduction

in deposition rate due to the use of the rotary porous

filter plate can be estimated from the deposition rate

determined without using the rotary porous filter plate and

controlled using an equation below. Portions of the

perforations 3 that are located at faces of the rotary

porous filter plate 1 are supposed to have the same diameter.

(Deposition rate) = (Deposition rate determined without

using filter plate) × (Sum of areas of portions of perforations / Surface area of filter plate)

When the deposition rate determined without using the filter plate is, for example, 100 nm/min and the percentage of the sum of the areas of the portions of the perforations in the surface area of the filter plate is 50% or 90%, the deposition rate calculated is 50 or 90 nm/min, respectively. In order to form a layer, the percentage is preferably large. Furthermore, in order to reduce the weight of the filter plate, the percentage is preferably large. Therefore, for both faces of the rotary porous filter plate 1, the term (Sum of areas of portions of perforations / Surface area of filter plate) is preferably 80% or more and more preferably 90%. In consideration of technical constraints on perforating and in consideration of the mechanical strength of the filter plate, the upper limit thereof is about 95%.

When the sum of the areas of the portions of the perforations is large, the fine particles flying at high speed pass through the perforations but the fine particles flying at low speed are trapped in the perforations while the filter plate is being rotated at a constant speed. A small number of cluster particles adhere to regions of a face of the rotary plate on which the fine particles are incident, the regions being outside the perforations. The following speed, length, and size need to be determined such that the fine particles which fly at low speed and which are

therefore transformed into droplets can be securely trapped: the rotation speed of the filter plate, the length of the perforations extending through the filter plate, the maximum size obtained by measuring each perforation in the circumferential direction of the filter plate (if the perforation is circular in cross section, the maximum size is equal to the diameter of the perforation).

When portions of the perforations 3 that are exposed at a face 2 of the rotary porous filter plate 1 have a circular shape As shown in Fig. 2, the maximum speed Vmax (in mm/second) of the fine particles that can be trapped by the rotary porous filter plate 1 is given by the equation Vmax = $(1 / 2) h\omega / \tan^{-1}(X / 2R)$, wherein X represents the diameter thereof, R represents the distance between the center line of the rotary shaft 4 connected to the rotary porous filter plate 1 and the center line of one of the perforations 3, h represents the length (in mm) of the perforations extending through the rotary porous filter plate 1 in the flight direction of the fine particles, and ω represents the angular speed (in radians/second) of the rotation of the rotary porous filter plate 1. The fine particles flying at a speed exceeding the maximum speed Vmax pass through the perforations to deposit on the substrate but the fine particles flying at a speed less than or equal to the maximum speed Vmax are trapped in the perforations of the rotary porous filter plate 1.

- 10 -

When the exit of each perforation has a diameter less than that of the entrance thereof as shown in Fig. 3, fine particles flying at a speed less than or equal to the speed given by the formula $(1 / 2)h\omega / \tan^{-1}(X / 2R)$ are trapped, wherein X represents the diameter of the entrance thereof. Furthermore, if the inequality $X - 2X' > 0$ holds, the fine particles flying at a speed greater than or equal to the speed given by the formula $(1 / 2)h\omega / \tan^{-1}(X - X' / 2R)$ are trapped, wherein X' represents the diameter of the exit thereof.

In order to cause the maximum speed of the fine particles trapped in the perforations close to the rotary shaft to agree with the maximum speed of the fine particles trapped in the perforations close to the edge of the rotary porous filter plate 1, the perforations close to the rotary shaft need to have diameters less than that of the perforations close to the edge thereof. That is, the more close to the edge of the rotary porous filter plate the perforations are, the larger diameters the perforations have. Trapping properties of the rotary porous filter plate 1 can be flexibly varied in such a manner that the diameter X and shape of the perforations 3 are varied depending on the positions on the rotary porous filter plate 1.

Fig. 4 shows a rotary porous filter plate in cross section in the thickness direction thereof. One of perforations extending through the rotary porous filter

- 11 -

plate is shown in this figure. This perforation 3 is designed such that the diameter X of an intermediate portion of this perforation 3 is greater than those of end portions thereof. Therefore, the wall of this perforation is curved. Trapped fine particles are gathered in a wide center region of this perforation 3 and thus are prevented from being released.

Fig. 5 shows a rotary porous filter plate 1 in cross section in the circumferential direction of this rotary porous filter plate 1. One of perforations extending through this rotary porous filter plate 1 is shown in this figure. The center line of this perforation 3 is tilted in the circumferential direction of this rotary porous filter plate 1, that is, the rotation direction thereof. The center line of this perforation 3 may extend straight in the circumferential direction. Alternatively, the center line of this perforation 3 may be curved along the circumference of this rotary plate, that is, this perforation 3 may be curved. If this perforation, as well as that perforation extending straight through that rotary porous filter plate vertically, has end portions and an intermediate portion having a diameter X greater than those of the end portions, trapped fine particles are gathered in a wide center region of this perforation and prevented from being released.

In Fig. 5, suppose that a target is disposed below this rotary porous filter plate 1, fine particles are incident on

the lower face of this rotary porous filter plate 1, and this perforation 3 moves with the rotation of this rotary porous filter plate 1 toward the left side. This perforation 3 needs to extend diagonally from an incident face toward the upper right. The following size and deviation are as defined in this figure: the maximum size X obtained by measuring the shape of this perforation 3 in the circumferential direction of the filter plate, the shape being exposed at a face of this rotary porous filter plate that faces the target, and the deviation (the difference between the right end of a lower hole and the left end of an upper hole in the plane of projection) d of this perforation 3, extending diagonally from the fine particle-incident face in the reverse rotation direction, in the plane of projection.

Since this perforation 3 is diagonal to a rotary face of this rotary porous filter plate 1, the fine particles flying at a speed less than or equal to the minimum speed Vmin of the fine particles that can pass through those perforations and the fine particles flying at a speed greater than or equal to the maximum speed Vmax of the fine particles that can pass through those perforations can be both trapped in this perforation 3, as described by the following equations: $V_{min} = (1 / 2)h\omega / \tan^{-1}((2X + d) / 2R)$ and $V_{max} = (1 / 2)h\omega / \tan^{-1}(d / 2R)$, wherein h represents the length of this perforation extending in this rotary

porous filter plate 1 in the flight direction of the fine particles (in mm); ω represents the angular speed of the rotation of this rotary porous filter plate 1 (in radians/second); R represents the distance between the center line of this perforation 3 and the center line of a rotary shaft connected to a face of this rotary porous filter plate 1 that faces the target; X represents the maximum size obtained by measuring the shape of this perforation 3 in the circumferential direction of the filter plate, the shape being exposed at the rotary porous filter plate face facing the target; and d represents the deviation of this perforation 3, extending diagonally from the fine particle-incident face in the reverse rotation direction, in the plane of projection.

Since this perforation is diagonal to the rotary face of this rotary porous filter plate, this rotary porous filter plate serves as a band-pass filter that can trap both the fine particles flying at a speed greater than or equal to the maximum speed of the fine particles that can pass through those perforations and the fine particles flying at a speed less than or equal to the minimum speed of the fine particles that can pass through those perforations, the maximum speed and minimum speed being set for each perforation. If the deviation is adjusted in such a manner that a portion of this perforation that exposed at a face of this rotary porous filter plate 1 on which the fine

particles incident and a portion of this perforation that exposed at a face of this rotary porous filter plate 1 from which the fine particles are released are formed so as to have different diameters, the maximum speed of the fine particles that can pass through this perforation can be varied.

As described above, the fine particles are incident on the rotary faces of the rotary porous filter plates perpendicularly to the rotary faces. However, if a face of a target is not parallel to a face of a substrate but is diagonal to the substrate face, the center line of each perforation may be diagonal to a rotary shaft connected to a rotary porous filter plate. Fig. 6 shows an example in which the direction of the center line of the perforation shown in Fig. 2 is tilted such that the incident direction of fine particles is tilted. Fig. 7 shows an example in which the direction of the center line of the diagonal perforation shown in Fig. 5 is tilted so as to correspond to the incident direction of fine particles. If fine particles are incident on a filter plate at an angle represented by ϕ in the rotation direction of this filter plate, the tilt angle of this perforation 3 needs to be varied as shown in Fig. 7.

In the above description, the perforations are circular in cross section and the size of each perforation is expressed as a diameter. The perforations may have any

shape, such as an elliptic shape or a polygonal shape, in cross section. Therefore, if the perforations are not circular in cross section, the maximum size obtained by measuring the cross-sectional shape of each perforation in the circumferential direction of a filter plate corresponds to the diameter of a perforation having a circular shape in cross section.

A method for manufacturing a rotary porous filter plate will now be described with reference to drawings. Fig. 8 illustrates a procedure for forming perforations in a metal disk by a photoresist process. One of the perforations is shown in this figure. A large number of the perforations 3 are precisely formed in the disk by a photolithographic process such that the perforations 3 are located at desired positions and have desired diameters. In view of the reduction in the load on a rotary system, the rotary porous filter plate is preferably made of a low-density material such as titanium. Alternatively, the rotary porous filter plate may be made of a metal material, such as stainless steel or aluminum alloy, releasing a small amount of gas in a vacuum.

Both faces of the metal disk 11 are coated with a photoresist agent 12. After the photoresist agent 12 is dried, photomasks 13 are arranged such that the perforations are formed at desired positions and have desired diameters. Light irradiation is then performed. After the resulting

metal disk 11 is rinsed, the metal disk 11 is etched with an
acidic or alkaline etching solution, whereby exposed
portions are removed. Etching is performed such that the
walls of the perforations are gouged. In the etching
operation, the perforations 3 are formed such that the
perforations 3 extend through the metal disk 11 and each
have end portions and an intermediate portion having a
diameter greater than those of the end portions. Finally,
the photoresist agent 12 is removed. This provides the
porous filter plate 1, in which the perforations 3 extend
through the metal disk 11.

When the metal disk is made of stainless steel, the
etching solution is usually a 38-42 Be ferric chloride
solution; a mixture of a ferric chloride solution and nitric
acid; or a mixture of 100 parts of hydrochloric acid, 6.5
parts of mercuric nitrate, and 100 parts of water. When the
metal disk is made of titanium, the etching solution is
usually a mixture of one part by volume of 40% hydrofluoric
acid and nine parts by volume of water (30-32°C) or a
mixture of a persulfate and a fluoride.

Fig. 9 illustrates another procedure for forming
perforations in a metal disk 11 by drilling or laser etching.
One of these perforations is shown in this figure. These
perforations are formed in this metal disk 11 made of
titanium or stainless steel using a drill, a high-power
laser beam, or a blanking machine such that these

- 17 -

perforations are located at desired positions and have desired diameters. The front and rear faces of this metal disk 11 are coated with an acidic or alkaline photoresist agent 12 and this metal disk 11 is immersed in an acid or alkali solution, whereby the walls of these perforations are etched. This allows these perforations 3 to each have end portions and an intermediate portion having a diameter greater than those of the end portions. After etching is finished, this photoresist agent 12 is removed. This provides this porous filter plate 1, in which these perforations 3 extend through this metal disk 11.

Fig. 10 shows an example having a perforation structure made by laminating three sheets. A rotary porous filter plate 1 is prepared by laminating a plurality of sheets A, B, and C. Holes can be formed in these sheets by photolithography, laser etching, drilling, blanking, or the like. The sheets A and C have holes having the same diameter and the holes of the sheet A are aligned with those of the sheet C. The sheet B has holes having a diameter greater than that of the holes of the sheets A and C and is sandwiched between the sheets A and C. The diameter X2 of the holes of the sheet located at an inner region of the filter plate is greater than the diameter X1 of the holes of the sheets located at outer regions thereof, that is, each perforation 3 has end portions and an intermediate portion having a diameter greater than those of the end portions.

Example 1

The following example will now be described in detail:
an example in which fine particles transformed into droplets
in a system, similar to that shown in Fig. 1, for a laser
ablation process are trapped.

Airborne fine particles were generated in such a manner
that an ArF excimer laser beam (a wavelength of 193 nm, FWHM
= 20 ns) was applied to a Si target, disposed in a vacuum
vessel evacuated to less than or equal to 5×10^{-7} Torr with
a turbomolecular pump, at an incident angle of 45 degrees,
whereby a Si layer was deposited on a glass substrate spaced
from the Si target at a distance of 50 mm. A rotary porous
filter plate, similar to that shown in Fig. 2, rotatable at
high speed, was placed between the target and the substrate
such that some of the fine particles were trapped with the
rotary porous filter plate.

The rotary porous filter plate was connected to a
rotary shaft parallel to the flight direction of the fine
particles fly. In order to agree with the maximum speed of
the fine particles trapped in perforations arranged close to
the center of the rotary porous filter plate with the
maximum speed of the fine particles trapped in perforations
arranged far from the center thereof, the perforations had
such sizes that diameter portions of the perforations that
extended in the circumferential direction made an internal
angle of 3.6 degrees with the rotary shaft. That is, X and

R shown in Fig. 2 were designed such that the equation $2\tan^{-1}(X / 2R) = 180$, i.e., the equation $X = 2.00R \times 10^{-2}$ (in mm) held.

The following diameter and distance were designed such that the equation $X = 2.00R \times 10^{-2}$ (in mm) held: the diameter (the rotation direction, i.e., the circumferential direction) X of each perforation located on the side on which the fine particles were incident and the distance R between the center line of the perforation and the center line of the rotary shaft. The rotary porous filter plate was prepared using a titanium disk having a diameter of 200 mm and a thickness h of 10 mm. The perforation had end portions and an intermediate portion having a diameter about 40% greater than those of the end portions. Fig. 11 shows the relationship between the rotation speed of the rotary porous filter plate and the maximum speed of the fine particles that can be trapped with the rotary porous filter plate. The following percentage was about 90%: the percentage of the sum of the areas of portions of the perforations in the surface area of the rotary porous filter plate. The fluence F of laser pulses was 4 J/cm^2, the repetition frequency was 10 Hz, and the substrate was maintained at room temperature.

The fine particles attached to silicon layers prepared as described above were observed with a scanning electron microscope (SEM). Figs. 12(a), 12(b), and 12(c) are images

of the silicon layers prepared by rotating the rotary porous filter plate at a speed of 1,000, 2,500, and 3,000 rpm, respectively. This shows that the fine particles are completely trapped with the rotary porous filter plate rotated at a speed of 3,000 rpm.

Industrial Applicability

An system and method according to the present invention are useful in depositing a thin film made of metal, semiconductor, ceramic, or the like on a substrate by a laser ablation process, a sputtering process, an arc discharge process and also useful in manufacturing a filter for trapping fine particles at low cost. Furthermore, the system and the method are useful in manufacturing a high-quality thin-film to which no droplets adhere and which is prevented from being contaminated with droplets that are trapped and then released.

Brief Description of the Drawings
[Fig. 1] Fig. 1 is a schematic view of an exemplary configuration of a laser ablation thin-film preparation system including a rotary filter.
[Fig. 2] Fig. 2 is a schematic perspective view of a rotary porous filter plate included in a system according to the present invention.
[Fig. 3] Fig. 3 is a sectional view of a rotary porous

- 21 -

filter plate, showing the relationship between the diameter of a perforation and the speed of fine particles.

[Fig. 4]   Fig. 4 is a sectional view of the rotary porous filter plate, showing the shape of a perforation in the depth direction of the perforation.

[Fig. 5]   Fig. 5 is a sectional view of a rotary porous filter plate having a diagonal perforation.

[Fig. 6]   Fig. 6 is a sectional view showing an example in which the direction of the center line of a perforation shown in Fig. 2 is tilted such that the incident direction of fine particles is tilted.

[Fig. 7]   Fig. 7 is a sectional view showing an example in which the direction of the center line of the diagonal perforation shown in Fig. 5 is tilted so as to correspond to the incident direction of fine particles.

[Fig. 8]   Fig. 8 is an illustration showing a procedure for manufacturing a rotary porous filter plate obtained by processing a metal disk by a photoresist process.

[Fig. 9]   Fig. 9 is an illustration showing a procedure for manufacturing a rotary porous filter plate by drilling or laser etching.

[Fig. 10]   Fig. 10 is an illustration showing a procedure for manufacturing a rotary porous filter plate by laminating three sheets.

[Fig. 11]   Fig. 11 is a graph showing the relationship between the rotation speed of a rotary porous filter plate

used in Example 1 and the maximum speed of fine particles that can be trapped with the rotary porous filter plate.

[Fig. 12]   Fig. 12 includes photographs, used instead of drawings showing SEM images of silicon layers prepared in Example 1 using a silicon target: Figs. 12(a), 12(b), and 12(c) are images of the silicon layers prepared by rotating this rotary porous filter plate at a speed of 1,000, 2,500, and 3,000 rpm, respectively.